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[Title of the Invention] X-RAY IMAGE DIAGNOSTIC APPARATUS

[Abstract]

[Object] To provide an X-ray image diagnostic apparatus capable of enhancing visibility from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption.

[Means for Solving the Problems] There is provided an X-ray image diagnostic apparatus for directing an X-ray beam emitted from an X-ray source to a subject to be measured through an attached filter, and capturing and displaying an X-ray image of said subject to be measured from the X-rays passing through said subject to be measured, said apparatus comprising: a member constituting said attached filter for modulating photon energy; filter control means for taking control to move said member and define a plurality of kinds of spectra of said X-ray beam based on the amount of said movement or on the thickness of said member; and combining means for combining X-ray images captured by the X-ray beams having said plurality of kinds of energy distributions to produce a display image.

[Scope of Claim for Patent]

[Claim 1] An X-ray image diagnostic apparatus for directing an X-ray beam emitted from an X-ray source to a subject to be measured through an attached filter, and capturing and displaying an X-ray image of said subject to be measured from the X-rays passing through said subject to be measured, said apparatus being characterized in comprising:

a member constituting said attached filter for modulating photon energy; filter control means for taking control to move said member and define a plurality of kinds of spectra of said X-ray beam based on the amount of said movement or on the thickness of said member; and combining means for combining X-ray images captured by the X-ray beams having said plurality of kinds of energy distributions to produce a display image.

[Claim 2] An X-ray image diagnostic apparatus for directing an X-ray beam emitted from an X-ray source to a subject to be measured through an attached filter, and capturing and displaying at least one frame of an X-ray image of said subject to be measured from the X-rays passing through said subject to be measured, said apparatus being characterized in comprising:

a member constituting said attached filter for modulating photon energy; filter control means for taking control to move said member and define a plurality of kinds of spectra of said X-ray beam based on the amount of said movement or on the thickness of said member; and means for emitting an X-ray beam having said defined X-ray spectrum a plural number of times within a frame for obtaining said X-ray image, to capture an X-ray image of said subject to be measured from the integrated amount resulting from the emission.

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to X-ray image diagnostic apparatuses having an attached filter (see "Therapeutic Radiation Data Book," issued in March, 1981 by Magbros Publishers, Inc., p. 19 (referred to as Non-patent Document 1 hereinbelow)), and particularly to techniques effective when applied to imaging of soft tissue using higher-energy X-rays.

[0002]

[Background] A conventional X-ray image diagnostic apparatus is comprised of an X-ray source for generating X-rays and directing them as an X-ray beam toward a subject to be measured, driving means for supplying said X-ray source with driving voltage and current, imaging means disposed opposite to the X-ray source, for imaging a difference in a distribution of X-ray transmission in the subject to be measured from X-rays passing through the subject to be measured as an X-ray image, and display means for displaying the X-ray image captured by the imaging means.

[0003] The X-ray sources that are generally employed include an X-ray tube sometimes referred to as a rotary anode X-ray tube. The rotary anode X-ray tube comprises a cathode comprising a filament, and an anode comprising a target that is carbon-based, for example, where a high voltage output by the driving means is applied across the cathode and anode. Moreover, a voltage sufficient to emit thermal electrons is applied to the filament. The X-ray tube is configured to accelerate the thermal electrons emitted from the filament by the high voltage

across the cathode and anode, and make them impinge upon the target in the anode to generate X-rays. The thus-generated X-rays are continuous X-rays added with characteristic X-rays, and have an energy range corresponding to the driving voltage applied across the cathode and anode.

[0004] On the other hand, recent advances in medical technology allows IVR (Interventional Radiology; X-ray fluoroscopic catheterization) using an X-ray image diagnostic apparatus to grow in use. Since IVR involves exposing the subject to be measured to X-rays during a time-consuming procedure, it is necessary to suppress the X-ray dose to as low a value as possible to reduce the exposure dose to the subject to be measured. Moreover, it is necessary to enhance visibility of the catheter, guide wire or the like by increasing the amount of the X-ray transmission in a region having a higher X-ray absorption, such as in the region of centrum. Thus, in IVR using the conventional X-ray image diagnostic apparatus, the subject to be measured is exposed only to a higher-energy X-ray beam in which lower-energy X-rays are attenuated by inserting a copper plate or the like serving as an attached filter having a thickness of the order of 0.1 – 0.4 mm into the X-ray source over its illumination surface.

[0005]

[Problem to be Solved by the Invention] The inventor of the present invention has reviewed the aforementioned conventional technique and eventually found the following problems. As discussed above, since the higher-energy X-ray beam has higher transmissibility as compared with the lower-energy X-ray beam, the beam is suitable in imaging

a region with relatively high contrast, such as a region including a portion that can be penetrated by X-rays and a portion that cannot be penetrated by X-rays, such as a catheter or a guide wire. On the other hand, when a human body is the subject to be measured, and especially when the subject to be imaged is defined in a portion having a smaller difference in X-ray absorption such as a lung field, the higher-energy X-ray beam poses a problem that it is not possible to perform imaging with subtle contrast due to its higher X-ray transmissivity.

[0006] A method for solving the problem that may be contemplated is one involving selecting use or non-use of the attached filter between a portion having a smaller difference in X-ray absorption such as the lung field and a portion having a larger difference in X-ray absorption, to handle imaging from a portion requiring subtle contrast to a portion requiring highly transmissive X-rays such as the centrum. However, IVR sometimes requires a catheter to be inserted from the iliac artery to the lung field. In such a case, there may be a method comprising applying X-ray fluoroscopy to a region from the femoral portion to the abdomen with the attached filter inserted, and applying X-ray fluoroscopy to the lung field, which is a focus of therapy, with no attached filter inserted.

[0007] However, to conduct insertion/removal of the attached filter in the course of X-ray fluoroscopy using the conventional X-ray image diagnostic apparatus, generation of X-ray beam must be briefly interrupted during the attached filter insertion/removal operations in view of the X-ray exposure to the subject. In other words, there is a problem that IVR must be interrupted in

the mid course, resulting in an increased time required in IVR.

[0008] Furthermore, it may be contemplated to employ a method using what is generally referred to as energy subtraction. Specifically, the driving voltage and driving current supplied to the X-ray source are modulated in real time and a higher-energy X-ray beam and a lower-energy X-ray beam are alternately emitted to thereby obtain a desired X-ray image. However, in using energy subtraction, the driving voltage and driving current must be modulated in real time, although this is relatively time-consuming, and therefore, the time required in one run of measurement is lengthened, leading to a problem that diagnostic or therapeutic efficiency is lowered.

[0009] An object of the present invention is to provide an X-ray image diagnostic apparatus capable of enhancing visibility from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption.

[0010] Another object of the present invention is to provide an X-ray image diagnostic apparatus capable of performing IVR without interrupting emission of an X-ray beam.

[0011] Still another object of the present invention is to provide an X-ray image diagnostic apparatus capable of consecutively performing capture of an X-ray image with higher-energy X-rays and that with lower-energy X-rays.

[0012] Yet still another object of the present invention is to provide an X-ray image diagnostic apparatus capable of improving diagnostic efficiency.

These and other objects and novel features of the present invention will become better understood from the following detailed description and the accompanying drawings.

[0013]

[Means for Solving the Problems] Representative ones of several aspects of the invention disclosed herein are summarized as follows:

(1) There is provided an X-ray image diagnostic apparatus for directing an X-ray beam emitted from an X-ray source to a subject to be measured through an attached filter, and capturing and displaying an X-ray image of said subject to be measured from the X-rays passing through said subject to be measured, said apparatus comprising: a member constituting said attached filter for modulating photon energy; filter control means for taking control to move said member and define a plurality of kinds of spectra of said X-ray beam based on the amount of said movement or on the thickness of said member; and combining means for combining X-ray images captured by the X-ray beams having said plurality of kinds of energy distributions to produce a display image.

[0014] (2) There is also provided an X-ray image diagnostic apparatus for directing an X-ray beam emitted from an X-ray source to a subject to be measured through an attached filter, and capturing and displaying at least one frame of an X-ray image of said subject to be measured from the X-rays passing through said subject to be measured, said apparatus comprising: a member constituting said attached filter for modulating photon energy; filter control means for taking control to move said member and define a plurality of kinds of spectra of

said X-ray beam based on the amount of said movement or on the thickness of said member; and means for emitting an X-ray beam having said defined X-ray spectrum a plural number of times within a frame for obtaining said X-ray image, to capture an X-ray image of said subject to be measured from the integrated amount resulting from the emission.

[0015] (3) There is provided the X-ray image diagnostic apparatus as described above regarding (1) or (2), wherein: said X-ray source comprises means for emitting a pulsed X-ray beam.

[0016] (4) There is provided the X-ray image diagnostic apparatus as described above regarding (3), wherein: an interval of emission of said X-ray beam is defined to be equal to or less than an imaging shot cycle of said X-ray image.

[0017] (5) There is provided the X-ray image diagnostic apparatus as described above regarding (3) or (4), wherein: the time at which said attached filter is inserted is synchronized with the time at which said X-ray beam is emitted.

[0018] (6) There is provided the X-ray image diagnostic apparatus as described above regarding any one of (1) – (5), wherein: said combining means produces a display image from successively captured X-ray images.

[0019] (7) There is provided the X-ray image diagnostic apparatus as described above regarding any one of (1) – (6), wherein: said attached filter is configured to have alternately disposed opening portion and absorbing portion, said opening portion not comprising said member for modulating photon energy, and said absorbing portion comprising said member for modulating

photon energy.

[0020] (8) There is provided the X-ray image diagnostic apparatus as described above regarding (7), wherein: said member for modulating photon energy is comprised of two or more members having different rates of reduction of the relative photon count in the lower-energy portion of said X-ray beam.

[0021] According to the means described regarding (1) and (3) – (8), for example, an attached filter is disposed adjacent to the illumination surface of the X-ray source, which corresponds to coverage of an X-ray beam. The attached filter is controlled by the filter control means in movement or thickness of the member for modulating photon energy. Therefore, an X-ray beam emitted from the X-ray source through the attached filter toward the subject to be measured has its spectrum controlled by the filter control means, and an X-ray image of the subject to be measured is captured by an X-ray beam having any one of a plurality of kinds of energy distributions, i.e., an X-ray beam having any one of a plurality of kinds of spectra varying by the filter control means.

[0022] Next, the combining means combines X-ray images captured by the X-ray beams having a plurality of kinds of energy distributions, and the combined image is made to serve as a display image, whereby visibility can be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption.

[0023] Therefore, even when IVR is performed on a subject to be imaged such as the lung field, display of an X-ray image with subtle contrast can be achieved while

fully maintaining contrast of the catheter or guide wire, and IVR can be achieved without interrupting emission of the X-ray beam. Particularly, even when therapy is performed on the lung field by inserting a catheter from the femoral portion, the therapy can be achieved without interrupting IVR, and therefore, the time required in IVR can be reduced, as a result of which the exposure dose to the subject to be measured can be reduced.

[0024] Moreover, since it is possible to reduce the time required in therapy, there is also provided an effect that stress placed on the subject to be measured can be reduced.

[0025] Furthermore, when the present invention is applied in diagnosis, visibility can also be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption, thus providing an effect that diagnostic efficiency can be improved.

[0026] According to the means described regarding (2), for example, an attached filter is disposed adjacent to the illumination surface of the X-ray source, which corresponds to coverage of an X-ray beam. The attached filter is controlled by the filter control means in movement or thickness of the member for modulating photon energy. Therefore, an X-ray beam emitted from the X-ray source through the attached filter toward the subject to be measured has its spectrum controlled by the filter control means, and an X-ray image of the subject to be measured is captured by an X-ray beam having any one of a plurality of kinds of energy distributions, i.e., an X-ray beam having any one of a plurality of kinds of spectra varying by the filter control means. At that

time, an X-ray beam having an X-ray spectrum defined by the filter control means is emitted a plural number of times within a frame for obtaining an X-ray image, to capture an X-ray image of said subject to be measured from the integrated amount resulting from the emission, whereby imaging by X-ray beams with certain kinds of X-ray spectra can be achieved in one imaging operation. That is, an X-ray image in which X-ray images each captured by an X-ray beam with a given X-ray spectrum are combined can be obtained, and thus, visibility can be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption. Thus, similar effects to those in the X-ray image diagnostic apparatus described above regarding (1) and (3) – (8) can be obtained.

[0027] Furthermore, since imaging by X-ray beams with certain kinds of X-ray spectra and addition (integration) of the captured X-ray images can be achieved in one imaging operation, it is possible to quickly acquire (capture) a combined X-ray image.

[0028]

[Embodiments of the Invention] The present invention will now be described in detail with reference to embodiments of the invention shown in the accompanying drawings. Parts having like functions are designated by like symbols throughout the drawings for explaining the embodiments of the invention, and repetitive explanation thereof will be omitted.

[0029] **(Embodiment 1)**

«Overview of a Configuration» FIG. 1 is a diagram for explaining an overview of a configuration of an X-ray image diagnostic apparatus in Embodiment 1 of the present

invention, where reference numeral 101 designates an X-ray sensor, reference numeral 102 designates a first image memory, reference numeral 103 designates a second image memory, reference numeral 104 designates image processing means (combining means), reference numeral 105 designates display means, reference numeral 106 designates an X-ray source, reference numeral 107 designates an attached filter section, and reference numeral 108 designates X-ray control means (filter control means).

[0030] In FIG. 1, the X-ray sensor 101 is well-known detecting means for detecting a distribution of the amount of transmission of an X-ray beam passing through a subject to be measured (not shown), i.e., an X-ray image of the subject to be measured, and converting it to electric signals, and is constructed from, for example, a well-known X-ray image intensifier (designated as "X-ray I. I." hereinbelow) and a television camera. Embodiment 1 will be specifically described regarding a case in which a CCD camera is used as the television camera, for immediately reading electrical charges caused by exposure, transferring them to a register, and enabling next exposure immediately after the foregoing readout. It will be easily recognized that the television cameras that may be employed include a CCD camera for reading electrical charges caused by exposure on a frame-by-frame basis and transferring them to a register, and a camera using a pickup tube. Moreover, it will be easily recognized that a similar effect can be obtained when the X-ray sensor 101 is substituted with a two-dimensional X-ray detector using well-known TFT elements or the like.

[0031] The first and second image memories 102, 103

are well-known storage means for storing therein an X-ray image (after being converted into digital information) output by the X-ray sensor 101 and supplying the stored X-ray image to the image processing means 103 as needed, and may be implemented by, for example, a main memory in a well-known information processing apparatus comprising the X-ray image diagnostic apparatus in Embodiment 1 or a well-known external storage device connected to the information processing apparatus.

[0032] The image processing means 104 may be implemented by, for example, a program running on the information processing apparatus comprising the X-ray image diagnostic apparatus in Embodiment 1, and constitutes means for performing well-known image correction on an X-ray image read from the first and second image memories 102, 103, and addition or the like of X-ray images after image processing. The additive processing here may include, for example, a method of additive processing for adding pixel values in X-ray images stored in the image memories 102, 103 on a pixel-by-pixel basis, and a method of applying spatial filtering of different types to respective X-ray images and then performing additive processing, although it will be easily recognized that the present invention is not limited thereto and other additive processing may be employed. It will be also easily recognized that the X-ray images may be separately displayed without additive processing depending upon an operational command from operation input means (not shown). Moreover, the image processing means 104 outputs the X-ray image read from the first and second image memories 102, 103 and subjected to given processing to the display means 105 as

a display image.

[0033] The display means 105 is well-known display means for displaying a display image output by the image processing means 104 on its display screen, and is a display device using, for example, a well-known CRT (Cathode Ray Tube) or a liquid crystal display device.

[0034] The X-ray source 106 is comprised of an X-ray tube (not shown) for generating X-rays and directing an X-ray beam toward a subject to be measured (not shown), and driving means (not shown) for supplying driving voltage/current to the X-ray tube, and emits a pulsed X-ray beam based on an X-ray emission command from the X-ray control means 108.

[0035] The attached filter section 107 is comprised of an attached filter unit disposed adjacent to the illumination surface of the X-ray source 106, and attached filter driving means for supporting the attached filter unit and driving it in synchronization with a frame signal. The attached filter unit is provided with an attached filter for blocking lower-energy X-rays in an X-ray beam and selectively permitting only higher-energy X-rays therein to pass through. The attached filter driving means is for insertion and removal of the attached filter disposed in the attached filter unit. The attached filter section 107 is thus configured to perform alternate emission of an X-ray beam containing lower-energy X-rays and a higher-energy X-ray beam in which lower-energy X-rays are attenuated. Specifically, by constructing the attached filter from a member for reducing the number of photons with lower photon energy in an X-ray spectrum of an X-ray beam emitted from the X-ray source 106, and controlling movement (the amount of

movement) of the attached filter, illumination by the higher-energy X-ray beam and by the lower-energy X-ray beam are alternately performed while controlling an X-ray beam emitted to the subject to be measured as to whether it has an X-ray spectrum with a reduced number of photons having lower photon energy (higher-energy X-ray beam), or it has an X-ray spectrum with a non-reduced number of photons having lower photon energy (lower-energy X-ray beam). However, since the spectrum of the X-ray beam varies depending upon a thickness as well as a kind of the material of the member constituting the attached filter, it will be easily recognized that emission of a higher-energy X-ray beam or a lower-energy X-ray beam may be controlled based on the thickness of the member constituting the attached filter. A detailed description of the configuration of the attached filter section 107 in Embodiment 1 will be discussed later. Moreover, as for an effect of the attached filter on the X-ray spectrum, see Non-patent Document 1.

[0036] The X-ray control means 108 is means for controlling the operation of several sections, and may be implemented by, for example, a program running on the information processing apparatus comprising the X-ray image diagnostic apparatus in Embodiment 1.

[0037] Next, FIG. 2 shows a diagram for explaining an imaging operation by the X-ray image diagnostic apparatus in Embodiment 1, and the operation of the X-ray image diagnostic apparatus in Embodiment 1 will be described hereinbelow with reference to FIG. 2. In the following description, an operation mode generally referred to as X-ray fluoroscopy, with which continuously captured X-ray images are displayed in real time, will be

first described.

[0038] First, upon a start command for measurement in the X-ray fluoroscopy mode from the operation input means (not shown), the X-ray control means 108 sends a signal to command the X-ray source 106 to emit an X-ray beam. In Embodiment 1, the command signal to emit an X-ray beam corresponds to first and second X-ray emission signals, and X-ray conditions (representing the driving voltage and driving current of the X-ray source 106). Moreover, the X-ray control means 108 sends a frame signal, the first and second X-ray emission signals, and an attached filter selection signal to the attached filter section 107.

[0039] The X-ray source 106 handles the first and second X-ray emission signals equivalently, and a drive control circuit (not shown) supplies drive power having the driving voltage and driving current specified by the X-ray conditions to the X-ray source 106 based on the first and second X-ray emission signal. It should be noted that in Embodiment 1, emission of the X-ray beam is achieved by alternately repeating a frame (T1 – T2) having 2 bursts of X-ray emission (indicated by ①, ② and ③, ④) within a period of one frame and a frame (T2 – T3) having no X-ray emission within a period of one frame, as shown in FIG. 2.

[0040] In this condition, the X-ray image diagnostic apparatus according to Embodiment 1 employs a CCD camera for immediately reading electrical charges caused by exposure, transferring them to a register, and enabling next exposure immediately after the foregoing readout as discussed above, and therefore, an X-ray image captured by the first burst of X-ray emission (indicated by ①)

within a period of a frame indicated by T1 – T2, for example, is read within the period of a frame T1 – T2. On the other hand, an X-ray image captured by the second burst of X-ray emission (indicated by ②) is read within a period of a frame (indicated by ②) following the period of a frame in which the X-ray emission is performed. By thus performing two bursts of X-ray emission, i.e., two shots of capture of an X-ray image, in a period of one frame, an interval from capture of an X-ray image indicated by ①, ③ to capture of an X-ray image indicated by ②, ④ is reduced, and image quality of an X-ray image can be prevented from degradation associated with misalignment of the subject to be measured or a portion to be imaged or the like.

[0041] At that time, the attached filter section 107 modulates filtering of an X-ray beam, i.e., quality of an X-ray beam, by inserting the attached filter in front of the X-ray source 106 in synchronization with the frame signal and first and second X-ray emission signals. In particular, in two bursts of X-ray emission within a period of one frame, capture of X-ray images with X-ray beams having different quality is achieved by inserting one attached filter in the first burst of X-ray emission and a different attached filter in the second burst of X-ray emission, or by inserting no attached filter in either one of the first or second burst of X-ray emission.

[0042] An X-ray image indicated by ① captured by the first burst of X-ray emission, which is read in the period of a frame indicated by T1 – T2, is stored in the first image memory 102. An X-ray image indicated by ② captured by the second burst of X-ray emission, which is read in the period of a frame indicated by T2 – T3, is

stored in the second image memory 103.

[0043] Thereafter, an X-ray image captured by the first burst of X-ray emission is stored in the first image memory 102, and an X-ray image captured by the second burst of X-ray emission is stored in the second image memory 103 in sequence.

[0044] The X-ray images stored in the first and second image memories 102, 103 are sequentially read by the image processing means 104, and subjected to image correction and additive processing. It should be noted that the additive processing here is applied to adjacent X-ray images that are captured in the same period of a frame. The X-ray image obtained after the additive processing is output by the image processing means 104 to the display means 105 as a display image, and displayed on the display screen of the display means 105.

[0045] «Configuration of the Attached Filter Section» FIG. 3 is a side view for explaining an overview of a configuration of the attached filter section in Embodiment 1, wherein reference numeral 301 designates attached filter driving means, reference numeral 302 designates an axle, reference numeral 303 designates an attached filter unit, reference numeral 304 designates a "Haube" (hood), and reference numeral 305 designates an X-ray emission port.

[0046] As shown in FIG. 3, the X-ray source 106 is housed in the hood 304, and the X-ray emission port 305 is disposed adjacent to the illumination surface for the X-ray beam in Embodiment 1. X-rays generated at the X-ray source 106 pass through the X-ray emission port 305 and are directed to the subject to be measured (not shown). Moreover, the attached filter driving means 301

is disposed adjacent to the X-ray emission port 305 and is configured to have the attached filter unit 303 disposed on the axle 302 projecting from the attached filter driving means 301. This configuration causes the attached filter unit 303 to be disposed within a path of the X-ray beam emitted through the X-ray emission port 305.

[0047] The axle 302 is driven by a motor (not shown), and is configured to rotate the attached filter unit 303 within the coverage of the X-ray beam by rotation around the axle 302.

[0048] FIG. 4 is a diagram for explaining an overview of a configuration of the attached filter unit in Embodiment 1, wherein reference numerals 401a – 401d designate attached filters, and reference numeral 402 designates an attached filter support.

[0049] As can be clearly seen from FIG. 4, the attached filter unit 303 in Embodiment 1 is secured to the attached filter support 402 by one end of each attached filter 401a – 401d so that the four attached filters 401a – 401d are arranged in a planar configuration. In this condition, each pair of the two adjacent attached filters 401a – 401d are arranged to form an angle of 90° with respect to each other. This arrangement of the attached filters 401a – 401d equally distributes their weight applied against the attached filter support 402. The attached filters 401a – 401d are suitably made from a light-weight material with higher absorption for lower-energy X-rays and lower absorption for higher-energy X-rays, such as, for example, copper (Cu), aluminum (Al), and copper+aluminum.

[0050] Moreover, since the attached filter support

402 is secured with the axle 302 positioned orthogonally to the attached filter unit 303, equal distribution of the weight of the attached filters 401a – 401d applied against the attached filter support 402 provides an effect that the cycle of rotation of the attached filter unit 303 under rotation of the axle 302 is prevented from being out of phase.

[0051] FIG. 5 is a diagram for explaining an overview of a configuration of the attached filter driving means in Embodiment 1, and FIG. 6 is a diagram for explaining an overview of a configuration of the motor control means in Embodiment 1.

[0052] As can be clearly seen from FIG. 5, the attached filter driving means in Embodiment 1 is comprised of a motor 501 disposed adjacent to the other end of the axle, and motor control means 502 for controlling the motor 501.

[0053] The motor 501 is a well-known motor attached with an encoder, for example, which rotationally operates to rotationally drive the axle based on a drive output by the motor control means 502, and outputs the angle of rotation to the motor control means 502 as an encoder output.

[0054] As shown in FIG. 6, the motor control means 502 is comprised of well-known motor driving means 601 for generating and supplying drive power for the motor 501, and drive control means 602 for generating a control signal for controlling rotation of the motor 501 based on the frame signal, first and second X-ray emission signals, and attached filter selection signal output by the X-ray control means 108, and on the output of the encoder.

[0055] FIG. 7 shows a diagram for explaining an

operation of inserting the attached filter in the X-ray image diagnostic apparatus in Embodiment 1, and the operation of the attached filter section in Embodiment 1 will be described below with reference to FIG. 7. For simplification of explanation, FIG. 7 illustrates the time of X-ray emission indicated by ① and ② and the time of insertion of the attached filter.

[0056] As discussed above, the X-ray control means 108 supplies first and second X-ray emission signals along with a frame signal. At that time, an X-ray image with a lower-energy X-ray beam is captured at the time of input of the first X-ray emission signal, the resulting X-ray image being one without inserting the attached filter. Next, an X-ray image with a higher-energy X-ray beam is captured at the time of input of the second X-ray emission signal, the resulting X-ray image being one with the attached filter inserted.

[0057] Therefore, the drive control means 602 in Embodiment 1 controls the rotational phase of the motor 501 so that none of the four attached filters 401a – 401d falls within the coverage of the X-ray beam at the first time of X-ray emission, which is indicated by S1 – S2.

[0058] On the other hand, the rotational phase of the motor 501 is controlled at the second time of X-ray emission, which is indicated by S4 – S5, so that any one of the four attached filters 401a – 401d is inserted within the coverage of the X-ray beam. Particularly, rotation of the motor 501 is controlled so that an attached filter is inserted into the coverage of the X-ray beam in a period of time indicated by S3 – S6, particularly, in a period of time of the second burst of X-ray emission indicated by S4 – S5. The filtering

operation of the attached filter section 107 for an X-ray beam is thus completely achieved.

[0059] FIG. 8 is a diagram for explaining an effect of the X-ray image diagnostic apparatus in Embodiment 1, wherein FIG. 8(a) represents an X-ray image captured without inserting the attached filter, FIG. 8(b) represents an X-ray image with the attached filter inserted, and FIG. 8(c) represents an X-ray image obtained by applying additive processing (combination) to the X-ray image captured without inserting the attached filter and that with the attached filter inserted, all of which are X-ray images particularly picking up the lung field.

[0060] Since the X-ray image in FIG. 8(a) is captured with no attached filter inserted, that is, captured with a lower-energy X-ray beam, the central portion of the image tends to be obscured in black, while it fully exhibits subtle contrast in the lung field.

[0061] On the other hand, since the X-ray image in FIG. 8(b) is captured with the attached filter inserted, that is, captured with a higher-energy X-ray beam, contrast in the spinal portion is fully maintained, although contrast in the lung field is lost.

[0062] Since the X-ray image diagnostic apparatus in Embodiment 1 is capable of displaying an X-ray image as an output image obtained by applying additive processing (combination) to an X-ray image captured without inserting an attached filter and that with the attached filter inserted, it is possible to display an X-ray image while maintaining both contrast in the spinal portion and that in the lung field, as shown in FIG. 8(c). That is, it is possible to display an X-ray image from a portion

having a smaller difference in X-ray absorption to a portion having a larger difference in absorption.

[0063] As described above, according to the X-ray image diagnostic apparatus in Embodiment 1, there is provided the attached filter unit 303 comprising the four attached filters 401a – 401d rotatably supported by the motor 501 serving as rotational support means, adjacent to the illumination surface of the X-ray source 106, which corresponds to coverage of an X-ray beam. The motor 501 is controlled in its rotation by the drive control means 602, and in Embodiment 1, the drive control means 602 controls rotation of the motor 501 to control insertion of the attached filters 401a – 401d into the coverage of the X-ray beam so that the energy distribution of the X-ray beam impinging upon the subject to be measured (not shown) is modulated. This allows capture of an X-ray image with a higher-energy X-ray beam while inserting the attached filters 401a – 401d into the coverage of the X-ray beam and capture of an X-ray image with a lower-energy X-ray beam without an inserted attached filter to be successively achieved. In this condition, the X-ray image with the higher-energy X-ray beam is sequentially stored in the first image memory 102 and that with the lower-energy X-ray beam is sequentially stored in the second image memory 103.

[0064] Next, the image processing means 104 reads X-ray images captured in the same period of a frame out of the first and second image memories 102, 103, and adds pixel values in the X-ray images on a pixel-by-pixel basis or adds them after applying different types of spatial filtering to the X-ray images, thereby producing a combined image of the X-ray image captured with a

higher-energy X-ray beam and that captured with a lower-energy X-ray beam. Next, the image processing means 104 displays the X-ray image obtained by the combination on a display screen of the display means 105 as a display image, and thus, visibility can be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption.

[0065] Therefore, even when IVR is performed on a subject to be imaged such as the lung field, display of an X-ray image with subtle contrast can be achieved while fully maintaining contrast of the catheter or guide wire, and IVR can be achieved without interrupting emission of the X-ray beam. Particularly, even when therapy is performed on the lung field by inserting a catheter from the femoral portion, the therapy can be achieved without interrupting IVR, and therefore, the time required in IVR can be reduced, as a result of which there is provided an effect that the exposure dose to the subject to be measured can be reduced. Moreover, since it is possible to reduce the time taken in therapy, there is also provided an effect that stress placed on the subject to be measured can be reduced.

[0066] Furthermore, when the X-ray image diagnostic apparatus in Embodiment 1 is applied in diagnosis, visibility can also be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption, thus providing an effect that diagnostic efficiency can be improved.

[0067] While in the X-ray image diagnostic apparatus in Embodiment 1, an X-ray image obtained by applying additive processing to an X-ray image with a lower-energy X-ray beam and that with a higher-energy X-ray beam is

served as a display image, it will be easily recognized that the present invention is not limited thereto and only an X-ray image with a lower-energy X-ray beam or only an X-ray image with a higher-energy X-ray beam, for example, may be displayed as a display image, or these images may be displayed on the same display screen.

[0068] (**Embodiment 2**)

FIG. 9 is a diagram for explaining an overview of a configuration of an X-ray image diagnostic apparatus in Embodiment 2 of the present invention, where reference numeral 901 designates an X-ray sensor, and reference numeral 902 designates an image memory. The configuration of other portions, except the X-ray sensor 901 and image memory 902, of the X-ray image diagnostic apparatus in Embodiment 2 is similar to that in the X-ray image diagnostic apparatus in Embodiment 1, and accordingly, the following description will be addressed to only the configuration of the X-ray sensor 901 and image memory 902, and an operation of capturing an X-ray image.

[0069] The X-ray sensor 901 is well-known detecting means for detecting a distribution of the amount of transmission of an X-ray beam passing through a subject to be measured (not shown), i.e., an X-ray image of the subject to be measured, and converting it to electric signals, and is constructed from, for example, a well-known X-ray I. I. and a television camera. Embodiment 2 will be described regarding a case in which a CCD camera or a pickup tube is used as the television camera, for reading electrical charges caused by exposure for each frame rate, and transferring them to a register. It will

be easily recognized that a similar effect can be obtained by a well-known two-dimensional X-ray detector employing TFT elements or the like, as the X-ray sensor 901.

[0070] The image memory 902 is well-known storage means for storing therein an X-ray image (after being converted into digital information) output by the X-ray sensor 101 and supplying the stored X-ray image to the image processing means 103 as needed, and may be implemented by, for example, a main memory in a well-known information processing apparatus comprising the X-ray image diagnostic apparatus in Embodiment 1 or a well-known external storage device connected to the information processing apparatus.

[0071] Next, an operation of the X-ray image diagnostic apparatus in Embodiment 2 will be described with reference to FIG. 9. Upon a start command for measurement in the X-ray fluoroscopy mode or X-ray imaging mode from the operation input means (not shown), the X-ray control means 108 sends a signal to command the X-ray source 106 to emit an X-ray beam, as in Embodiment 1. In Embodiment 2, the command signal to emit an X-ray beam corresponds to first and second X-ray emission signals and X-ray conditions (representing driving voltage and driving current of the X-ray source 106). Moreover, the X-ray control means 108 sends a frame signal, the first and second X-ray emission signals, and an attached filter selection signal to the attached filter section 107.

[0072] The X-ray source 106 is supplied with driving power specified by the X-ray conditions based on the first and second X-ray emission signals, upon which an X-

ray beam is generated and emitted. However, in the X-ray image diagnostic apparatus in Embodiment 2, a frame in which two bursts of X-ray emission is performed within a period of one frame consecutively occurs.

[0073] At that time, the attached filter section 107 modulates filtering of an X-ray beam, i.e., quality of an X-ray beam, by inserting the attached filter in front of the X-ray source 106 in synchronization with the frame signal and first and second X-ray emission signals. In particular, in two bursts of X-ray emission within a period of one frame, capture of X-ray images with X-ray beams having different quality is achieved by inserting one attached filter in the first burst of X-ray emission and a different attached filter in the second burst of X-ray emission, or by inserting no attached filter in either one of the first or second burst of X-ray emission.

[0074] In this condition, in Embodiment 2, an X-ray image with a lower-energy X-ray beam in the first burst of X-ray emission and an X-ray image with a higher-energy X-ray beam in the second burst of X-ray emission are captured within one imaging operation in a period of one frame. Specifically, by capturing an X-ray image in the second burst of X-ray emission following the first burst of X-ray emission without readout of electrical charges in the X-ray sensor 901 generated in the capture of the X-ray image in the first burst of X-ray emission, the X-ray sensor 901 accumulates additive (integrated) electrical charges of the first and second X-ray images, which means that additive processing is performed by the X-ray sensor 901.

[0075] Therefore, the X-ray image output by the X-ray sensor 901 and stored in the image memory 902 is an

additive X-ray image of an X-ray image with a lower-energy X-ray beam and an X-ray image with a higher-energy X-ray beam.

[0076] Next, the X-ray images stored in the image memory 902 are sequentially read by the image processing means 104, and subjected to image correction. The X-ray image obtained after image correction is output by the image processing means 104 to the display means 105 as a display image, and displayed on the display screen of the display means 105.

[0077] As described above, according to the X-ray image diagnostic apparatus in Embodiment 2, there is provided the attached filter unit 303 comprising the four attached filters 401a – 401d rotatably supported by the motor 501 serving as rotational support means, adjacent to the illumination surface of the X-ray source 106, which corresponds to coverage of an X-ray beam. The motor 501 is controlled in its rotation by the drive control means 602, and in Embodiment 2, the drive control means 602 controls rotation of the motor 501 to control insertion of the attached filters 401a – 401d into the coverage of the X-ray beam so that the energy distribution of the X-ray beam impinging upon the subject to be measured (not shown) is modulated. This allows capture of an X-ray image with a higher-energy X-ray beam while inserting the attached filters 401a – 401d into the coverage of the X-ray beam and capture of an X-ray image with a lower-energy X-ray beam without an inserted attached filter to be successively achieved. In this condition, since the X-ray sensor 901 captures an X-ray image with a higher-energy X-ray beam and that with a lower-energy X-ray beam in one imaging operation to

thereby enable addition (combination) of the X-ray image captured with a higher-energy X-ray beam and that captured with a lower-energy X-ray beam, visibility can be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption. Thus, a similar effect to that in the aforementioned X-ray image diagnostic apparatus in Embodiment 1 can be obtained.

[0078] Moreover, since the X-ray image diagnostic apparatus in Embodiment 2 is capable of performing capture of an X-ray image while inserting the attached filters 401a – 401d and an X-ray image without inserting an attached filter as well as addition of the two X-ray images within a period of one frame, it is possible to acquire images quickly.

[0079] It should be noted that the effects of the X-ray image diagnostic apparatus in the present embodiments especially accrue to a medical X-ray image diagnostic apparatus with a human body as the subject to be measured.

[0080] Moreover, while the X-ray image diagnostic apparatus in the present embodiments is configured to have one type of attached filters provided in the attached filter unit 303, it will be easily recognized that the present invention is not limited thereto and it may be configured to have two or more different types of attached filters, for example, and perform X-ray imaging with a desired type of an attached filter based on an attached filter selection command supplied via the operation input means.

[0081] While the present invention made by the inventor has been described in particular with reference to the embodiments of the invention, it will be easily

recognized that the present invention is not limited thereto and may be practiced with various modifications without departing from the spirit and scope thereof.

[0082]

[Effects of the Invention] Effects provided by representative ones of several aspects of the invention disclosed herein are summarized as follows:

(1) Visibility can be enhanced from a portion having a smaller difference in X-ray absorption to a portion having a larger difference in absorption;

(2) IVR can be achieved without interrupting emission of an X-ray beam;

(3) X-ray imaging with higher-energy X-rays and with lower-energy X-rays can be performed in a consecutive and quick manner; and

(4) Diagnostic efficiency can be improved.

[Brief Description of the Drawings]

[FIG. 1] A diagram for explaining an overview of a configuration of an X-ray image diagnostic apparatus in one embodiment of the present invention.

[FIG. 2] A diagram for explaining an imaging operation in the X-ray image diagnostic apparatus in the present embodiment.

[FIG. 3] A side view for explaining an overview of a configuration of an attached filter section in Embodiment 1.

[FIG. 4] A diagram for explaining an overview of a configuration of an attached filter unit in Embodiment 1.

[FIG. 5] A diagram for explaining an overview of a configuration of attached filter driving means in Embodiment 1.

[FIG. 6] A diagram for explaining an overview of a configuration of motor control means in Embodiment 1.

[FIG. 7] A diagram for explaining an operation of inserting the attached filter in the X-ray image diagnostic apparatus in Embodiment 1.

[FIG. 8] A diagram for explaining an effect of the X-ray image diagnostic apparatus in Embodiment 1.

[FIG. 9] A diagram for explaining an overview of a configuration of the X-ray image diagnostic apparatus in Embodiment 2 of the present invention.

[Explanation of Reference Symbols]

101: X-ray sensor, 102: First image memory, 103: Second image memory, 104: Image processing means, 105: Display means, 106: X-ray source, 107: Attached filter section, 108: X-ray control means, 301: Attached filter driving means, 302: Axle, 303: Attached filter unit, 304: Hood, 305: X-ray emission port, 401a – 401d: Attached filters, 402: Attached filter support, 501: Motor, 502: Motor control means, 601: Motor driving means, 602: Drive control means, 901: X-ray sensor, and 902: Image memory.

SYMBOLS

(FIG. 1)

101 X-ray sensor

102 1^{st} image memory

103 2^{nd} image memory

104 Image processing means

105 Display means

106 X-ray source

107 Attached filter section

108 X-ray control means

(FIG. 2)

Frame signal (V-sync)

Time of X-ray emission

Read X-ray image X-ray image in ①...

(FIG. 3)

301 Attached filter driving means

302 Axle

303 Attached filter unit

304 Hood

305 X-ray emission port

(FIG. 4)

401a – 401d Attached filters

402 Attached filter support

(FIG. 5)

501 Motor

502 Motor control means

(FIG. 6)

601 Motor driving means

602 Drive control means

Frame signal

1st X-ray emission signal

2nd X-ray emission signal

Attached filter selection signal

Output of encoder

(FIG. 7)

Frame signal (V-sync)

Time of X-ray emission

1st X-ray emission signal

2nd X-ray emission signal

Time of attached filter insertion